Load cell dual-range calibration-force potential measurement error

Molecule excitement decline might explain why the use of a low-range calibration on a reference standard can lead to additional error. This article will explain what molecule excitement decline is, and what should be done to minimize the error associated with using a load cell at a high and low range. In the experiment we conducted at Morehouse, we chose a 10,000 lbf shear web load cell and tested repeatability of a 1,000 lbf test point when exercised to 10,000 lbf and when only exercised to 1,000 lbf.

Dual-range calibration is a calibration in which a force-measuring instrument is calibrated at two ranges. These ranges are typically a high and low range. An example of a dual-range calibration would be performing a calibration from 1,000 lbf through 10,000 lbf (high range), and then performing a calibration from 100 through 1,000 lbf (low range) on a 10,000 lbf force-measuring instrument.

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The test data is presented in Table 1. For the first test, the load cell was exercised to 10,000 lbf three times and then loaded to 1,000 lbf five times. Changes in the zero-force readings were treated in accordance with ASTM E74.13a Method (b) average zero method. The remainder of the tests was spread over time, and the load cell was exercised to 1,000 lbf three times before being loaded to 1,000 lbf five times.

The data in Table 1 was compared using ANOVA analysis. Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences among group means and their associated procedures. ANOVA allows us to know if there is an agreement between the means of several groups.

The data from the ANOVA analysis in Table 2 shows significant differences between the tests. The means are not all the same. The ANOVA test comparing 0hrs with 3hrs, 3hrs and 24hrs, 24hrs and 28hrs, and 168hrs and 188hrs did not show significant difference between the means at 24hrs and 28hrs, as well as 168hrs and 188hrs.

At the start of the test, it was thought that the molecule excitement decline would equalize within 24 hours. This was not the case. The molecules in the load cell continued to decline. When we decided to test the load cell again, about five days had passed since we had agreement of the means. The ANOVA analysis where we found agreement was indicated by a P-value of better than 0.05. The P-value is the probability of obtaining a result that is completely uncorrelated with the test variable.

The ANOVA analysis shown in Table 3 used a significance level (α) of 0.05. An Alpha of 0.05 indicates that a five percent risk difference exists to get a sample that is not representative of the population. At 168hrs and 188hrs, the P-value was 1. This indicates that there is a very high likelihood of obtaining similar averages by repeating this test. If we loaded the load cell today, we should expect the numbers to agree.

Explaining the error

The output of each test was analyzed, and the difference from the initial test, where the load cell was exercised to 10,000 lbf prior to loading to 1,000 lbf, was run (Table 4).

The load cell exhibited a decline in output, which correlated to the amount of time between the additional applications of forces. The potential error ranged from

Molecule Excitement Decline of a Shear Web Transducer

Force Applied LBF	First Test Exercised to 10,000 LBF	3 Hours Later Exercised to 1,000 LBF	Next Day AM Exercised to 1,000 LBF	Next Day PM Exercised to 1,000 LBF	Next Week Exercised to 1,000 LBF	Next Week Exercised to 1,000 LBF
Time	0	3HRS	24HRS	28HRS	168HRS	188HRS
1000	0.41095	0.41091	0.41088	0.41090	0.41057	0.41058
1000	0.41096	0.41091	0.41086	0.41087	0.41058	0.41059
1000	0.41096	0.41092	0.41085	0.41088	0.41059	0.41058
1000	0.41092	0.41089	0.41087	0.41089	0.41058	0.41058
1000	0.41095	0.41090	0.41089	0.41090	0.41059	0.41058
Average	0.41095	0.41091	0.41087	0.41089	0.41058	0.41058
Std Dev	0.000016	0.000011	0.000016	0.000013	0.000008	0.000004
Std Dev in LBF	0.040	0.028	0.038	0.032	0.020	0.011

TABLE 1.

ANOVA: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0	5	2.05474	0.410948	2.7E-10
3HRS	5	2.05453	0.410906	1.3E-10
24HRS	5	2.05435	0.41087	2.5E-10
28HRS	5	2.05444	0.410888	1.7E-10
168HRS	5	2.05291	0.410582	7E-11
188HRS	5	2.05291	0.410582	2E-11

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.036E-07	5	1.4076E-07	927.929670	1.24228E-26	2.62065414
Within Groups	3.64E-09	24	1.5166E-10			
Total	7.0732E-07	29				

TABLE 2.

Henry Zumbrun II *is president of Morehouse Instrument Company, York, Pennsylvania, where he has managed their force and torque calibration lab and services in the family-owned business since the 1990s. Morehouse was founded nearly 100 years ago; in that time, various family members developed and perfected the Morehouse Proving Ring—one of which is on the International Space Station—as well as instruments and machines for the precise measurement and calibration of the thrust generated by rocket and jet engines, such as universal calibrating machines, dead weight machines, and several general verification instruments related to force measurement.*

0.001 percent to 0.0089 percent. This error could be considerable when using the load cell as a secondary reference standard to calibrate other load cells. A Secondary Standard, as defined by ASTM E74-13a, is one that is calibrated by Primary Standards (deadweights) and has a test accuracy ratio of better than 0.05 percent. A maximum difference of 0.0089 percent was observed. On non-shear web type load cells, this error could exceed the range required by ASTM E74-13a for force measuring instruments used as Secondary Standards. If you are not sure if your load cells have this error, test them.

The average output of the tests was plotted as shown in Figures 1 and 2. The graph shows the cell to be repeatable at 168hrs and 188hrs. A trend line using a third order polynomial was plotted and came up with an R-squared value of 0.8561. This means the data set fits the line within 85.61 percent. An R-squared value of 1 would mean the regression line would perfectly fit the data.

Molecule excitement decline

A possible explanation of what is happening in the tests shown here:

To understand molecule excitement decline, we must first understand kinetic energy. The kinetic energy of an object is the energy that it possesses due to its motion. It is defined as the work needed to accelerate a body of a given mass from rest to its stated velocity. Having gained this energy during its acceleration, the body maintains the same kinetic energy unless its speed changes.

When the force-measuring device is loaded to capacity, the molecules inside the material reach resonate frequencies; we will refer to this as a "Happy State." As the instrument sits, the room temperature causes these molecules to begin to slow. Over time, these molecules will slow to a minimum. As these molecules slow, the kinetic energy decreases.

When the instrument is not loaded to full capacity, the kinetic energy will not reach its full "Happy State." The result of this is less molecule movement, resulting in a change in the load cell output. In our tests, the molecule decline stabilized at some point between 28hrs and 168hrs. This can be explained since the molecules in the material declined to a point where the molecules' frequencies matched that of the temperature of our calibration laboratory. Further molecule decline would continue to happen if the temperature were decreased.

Summary

Any force-measuring instrument may exhibit a similar molecule decline. Remember Newton's First Law of Motion? Things in motion tend to stay in motion; things at rest remain at rest. Exercising a load cell to capacity will put the molecules in motion. The molecule motion will decline over a period of time, and at some point, they will stabilize.

The load cell must be exercised to capacity prior to performing a calibration to put the molecules back in motion. This may be instrument-dependent. To minimize any chance of additional measuring error, Morehouse recommends loading the instrument to full capacity prior to using the device to calibrate any force point that is less than the full capacity to which the device was calibrated. For instruments used as Secondary Standards, it is suggested to use two load cells instead of calibrating two ranges on one load cell. To further support this, the limited instrument resolution on a low range calibration may be a dominant uncertainty contributor, resulting in larger expanded uncertainty than when compared with two separate load cells.

Author's note: Physicist and auditor Harry Moody will comment on our investigation into this kind of potential measurement error in TEST's next (June/July 2016) issue.

ANOVA: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
24HRS	5	-2.05435	-0.41087	2.5E-10
28HRS	5	-2.05444	-0.410888	1.7E-10

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	8.1E-10	1	8.1E-10	3.857142857	0.085135072	5.317655072
Within Groups	1.68E-09	8	2.1E-10			
Total	2.49E-09	9				

ANOVA: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
168HRS	5	2.05291	0.410582	7E-11
188HRS	5	2.05291	0.410582	2E-11

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0	1	0	0	1	5.317655072
Within Groups	3.6E-10	8	4.5E-11			
Total	3.6E-10	9				

TABLE 3.

Difference from initial calibration of low range					
	0 vs 3	0 Vs 24	0 Vs 28	0 vs 196	0 vs 196
mV/V	0.00004	0.00008	0.00006	0.00037	0.00037
In LBF	0.102241	0.189875	0.146058	0.890953	0.890953
In %	0.0010%	0.0019%	0.0015%	0.0089%	0.0089%

TABLE 4.

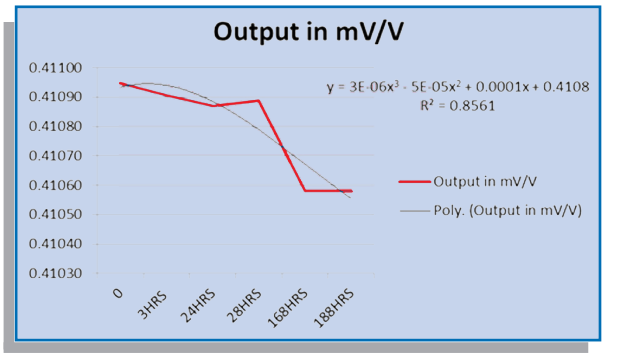

FIGURE 1.

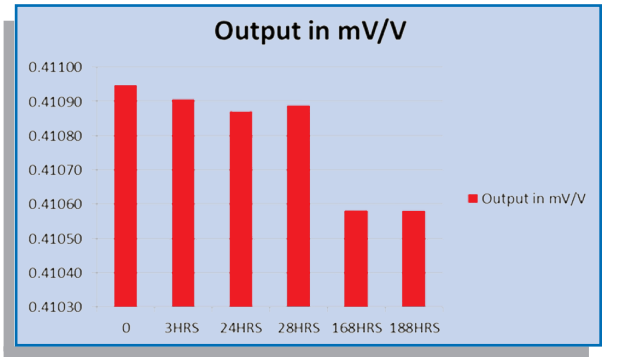

FIGURE 2.

***To continue this discussion with Henry Zumbrun, go to* www.testmagazine.biz/info.php/16am000**